Deep Convective Outflow, Convective Strength and Anvil Development: New Perspectives Based on CloudSat and CALIPSO

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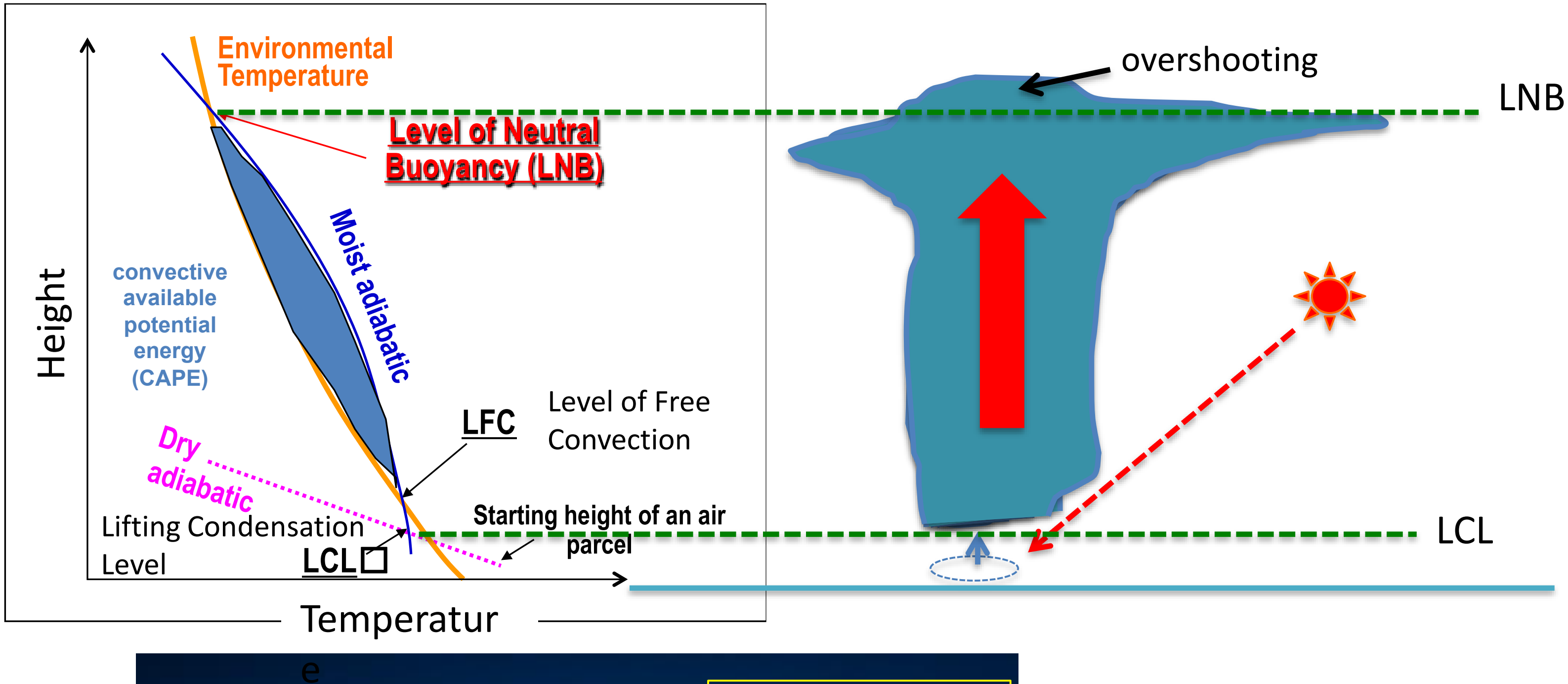
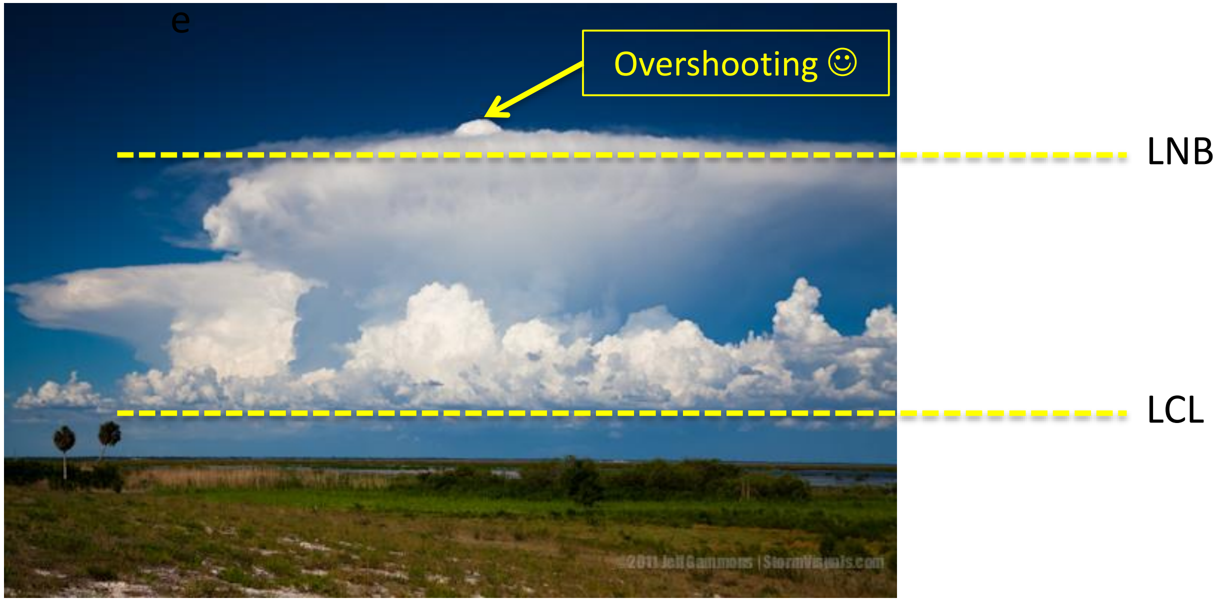
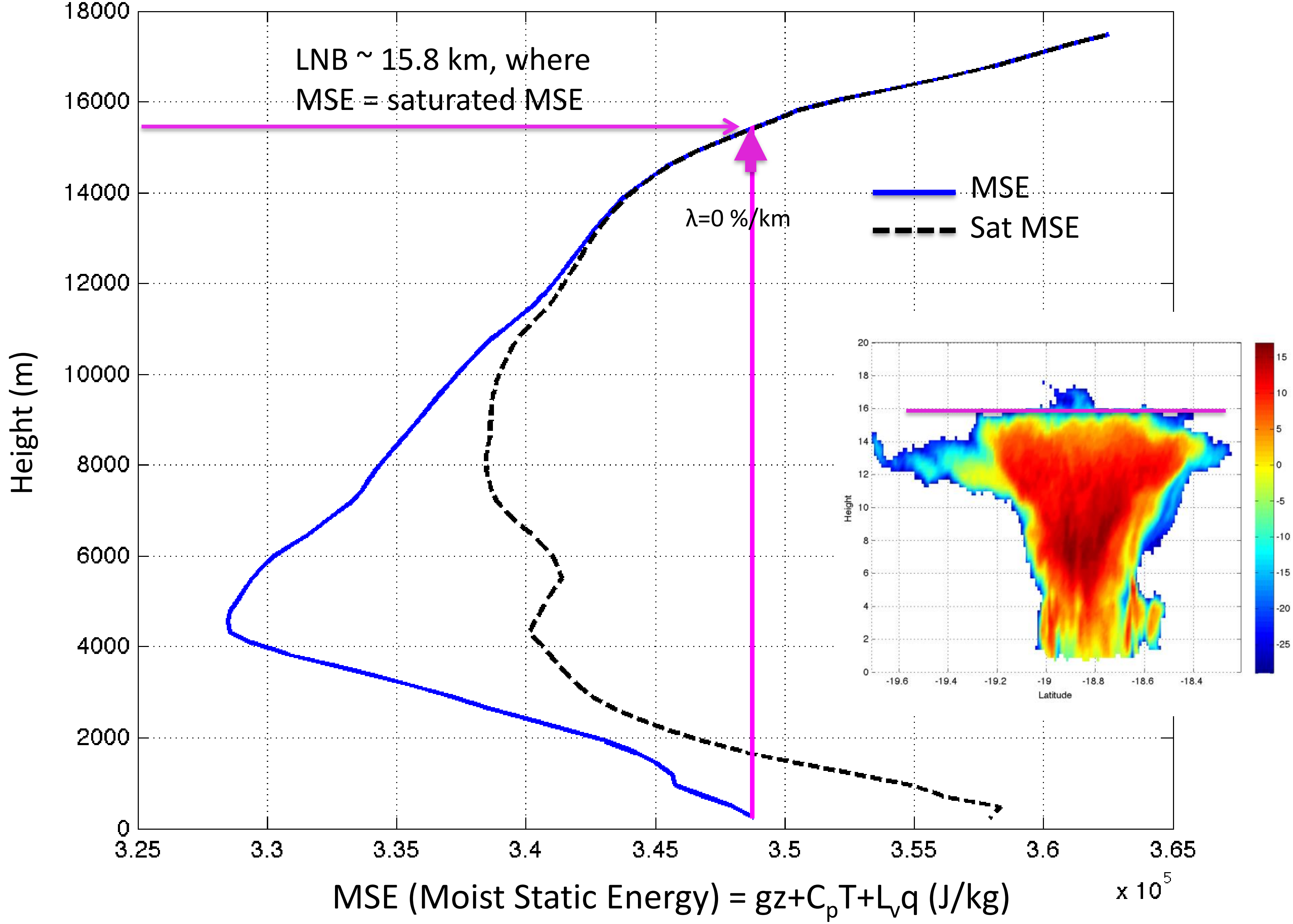
Parcel Theory: a simple path of a rising air parcel





Definition of LNB from Parcel Theory



Ideal World based on Parcel Theory | **Real World**

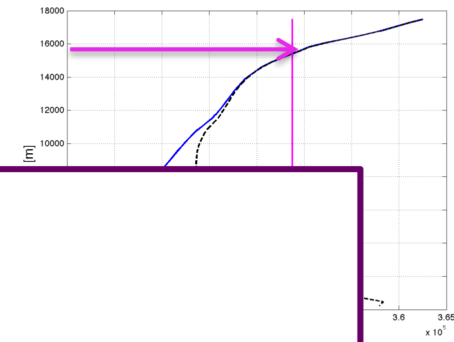
$$\lambda = 0$$

$$\lambda = \frac{1}{M}\frac{\partial M}{\partial z}$$: the rate of change of the mass flux into the plume with height

- No air mass interaction between the air parcel and its surrounding environment.
- Only accounts for the original condition of surface soundings.

- Convection interacts with the environment in complicated ways.
- Convective entrainment affects buoyancy.

Objective: Compare LNB based on Parcel Theory vs. Cloud Objects



LNB_sounding:

- Ba
  fro

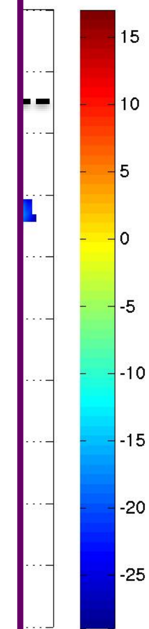
Radar reflectivity as a proxy for convective mass transport

G. L. Mullendore,[1] A. J. Homann,[1] K. Bevers,[2] and C. Schumacher[2]

Received 6 November 2008; revised 27 April 2009; accepted 11 June 2009; published 22 August 2009.

[1] More observations of vertical mass transport in deep convection are needed to improve dynamical understanding of detrainment processes and for verification of transport models. A methodology for using radar reflectivity as a direct observation of vertical transport of mass from the boundary layer to the upper troposphere and lower stratosphere is investigated, and the "level of maximum detrainment" (LMD) is proposed. The case investigated is the 26 January 1999 squall line from the Tropical Rainfall Measuring Mission Large-Scale Biosphere-Atmosphere field campaign. Echo top heights and dual-Doppler derived divergence profiles are used to define the mass detrainment range. Over 10% of anvil echo tops occurred above the sounding-derived level of neutral buoyancy of 15.4 km during the mature stage of the storm, and convective tops reached above 18 km. Anvil ice water content, with a simple correction for ice fall speed, is found to be a good proxy for both the LMD, which for the storm analyzed is 11.25 km, and for the detrainment range of 6 to 17 km. More cases need to be analyzed to confirm the strength of this methodology, but the case study presented shows a strong correlation between anvil properties determined from radar reflectivity and the mass detrainment profile. Thus, radar reflectivity can be used as an indicator of the LMD to test model convective and transport parameterizations.

Citation: Mullendore, G. L., A. J. Homann, K. Bevers, and C. Schumacher (2009), Radar reflectivity as a proxy for convective mass transport, *J. Geophys. Res.*, *114*, D16103, doi:10.1029/2008JD011431.



LNB_c

- LN
- LN
- LN
  lev
  column).

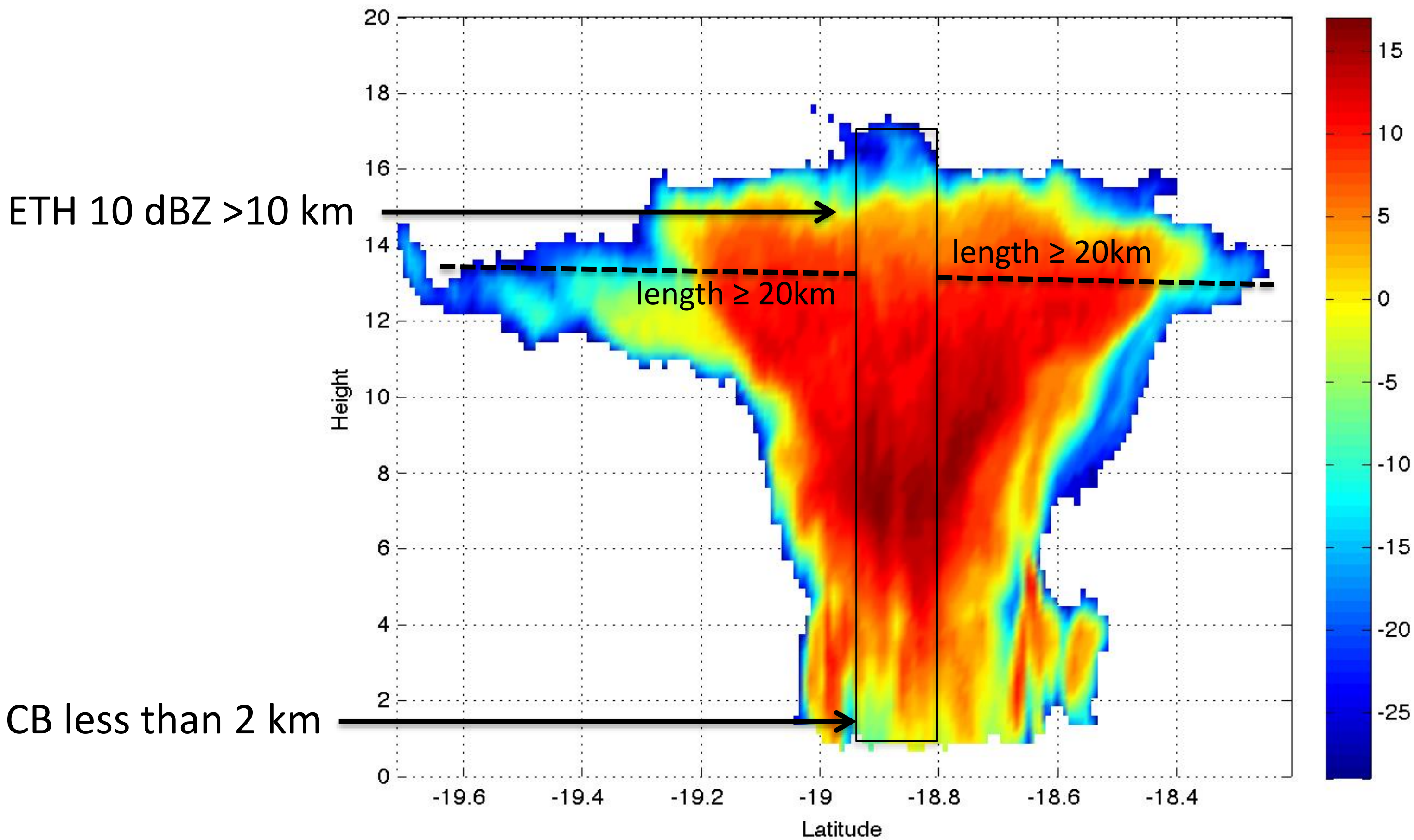
12)

A case study from the Tropical Rainfall Measuring Mission (TRMM) Large-scale Biosphere-Atmosphere (LBA) field campaign

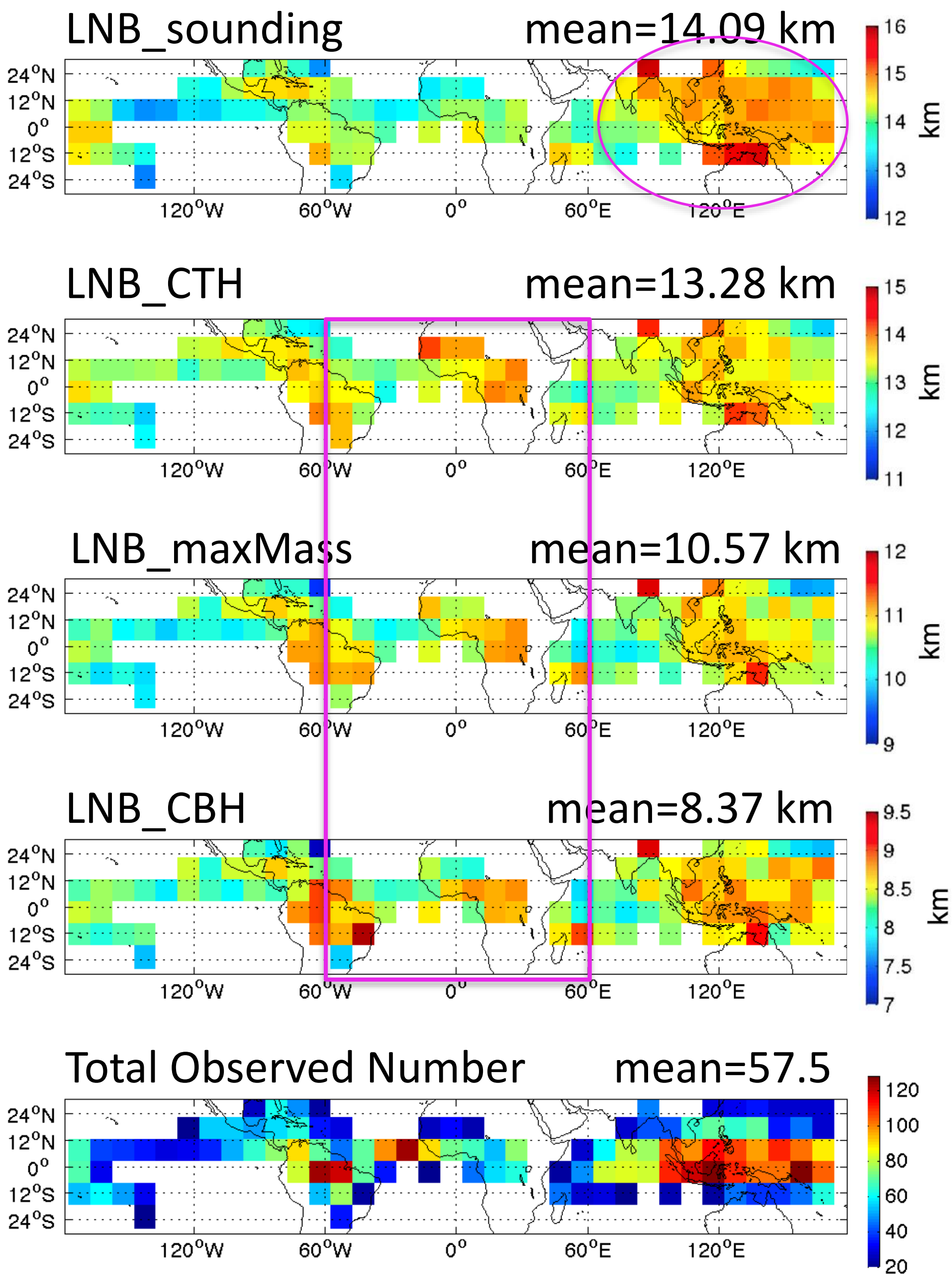
Only the first 20 km of the outflow is used to minimize ice sedimentation effect

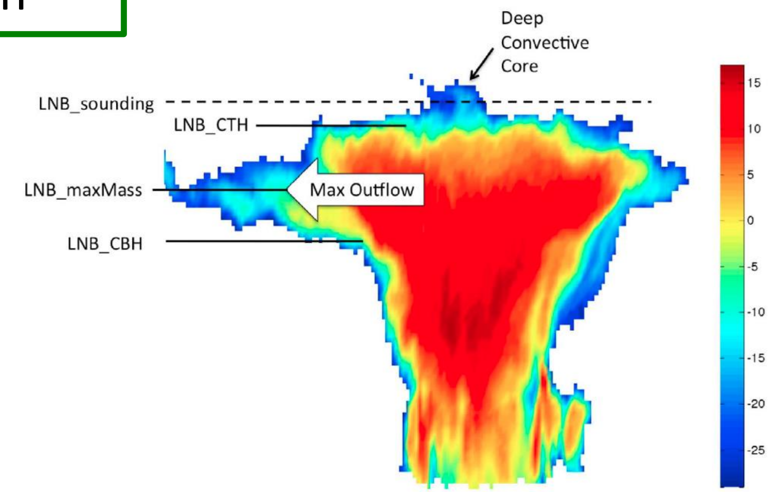
Selection of convective core and anvil object

(1) Cloud mask >20
(2) Find convective core (ETH 10dBZ >10 km, CB<2km, continuous radar echo from CB to CT)
(3) Find anvils (CB ≥ 5km & anvil length ≥ 20km)



Distribution of LNB_sounding vs. LNB_observation

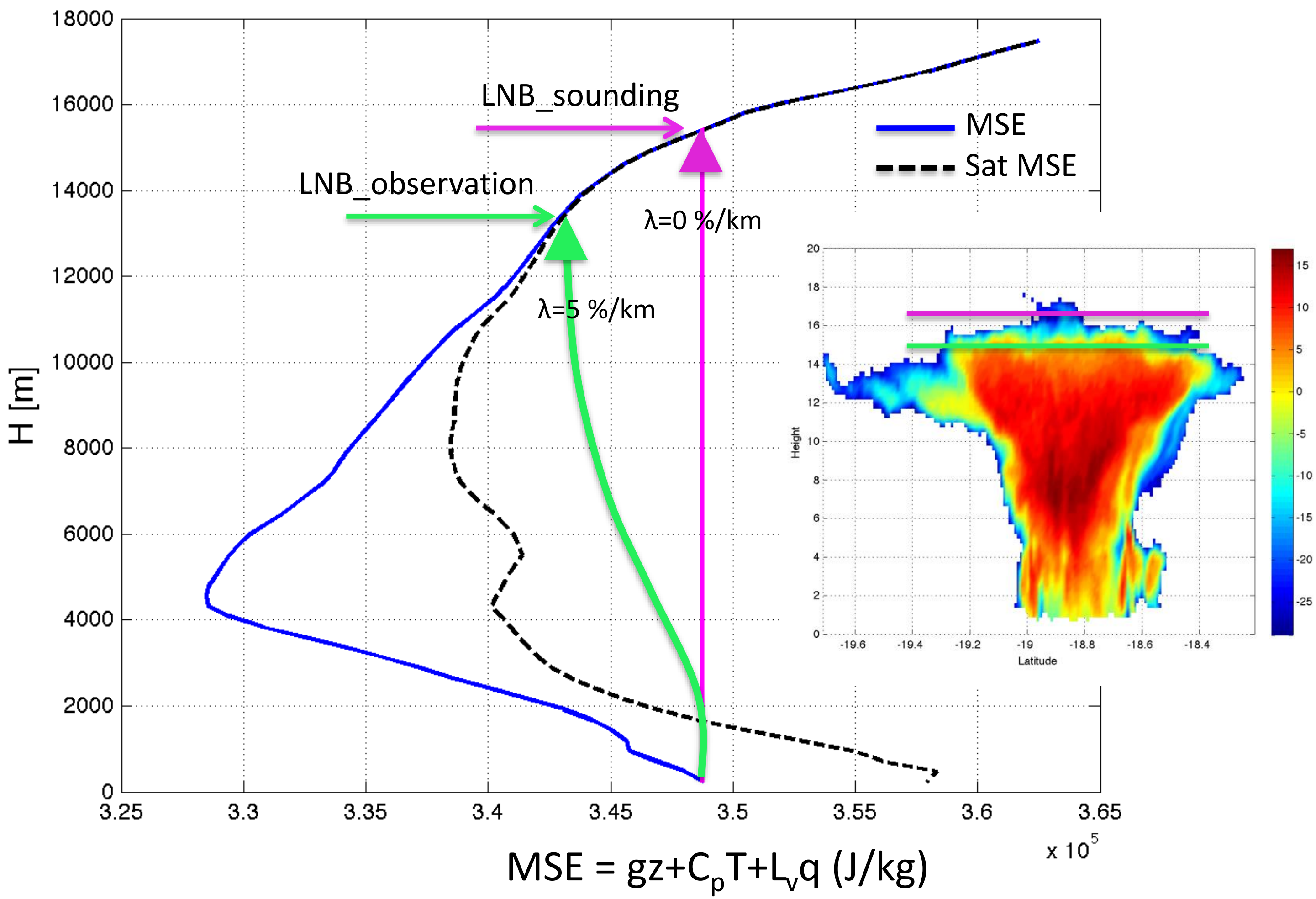




- LNB_sounding: the Warm Pool has the highest LNB.
- For LNB_observation, tropical Africa and Amazonia has the highest LNB.

The difference between LNB_sounding and LNB_observation

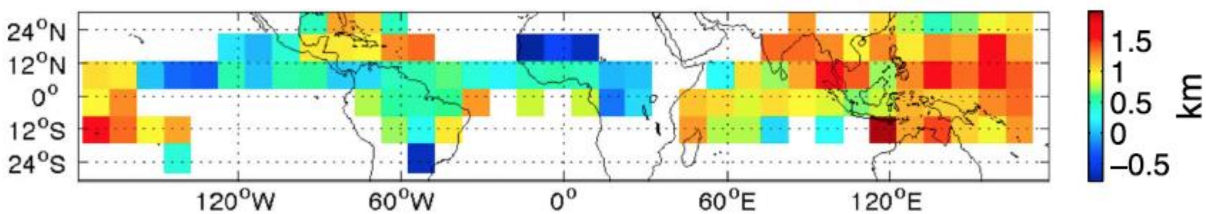
A measure of the magnitude of the entrainment effect



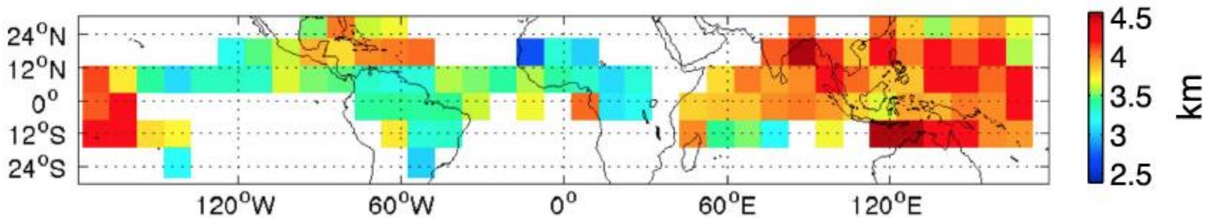
The difference between LNB_sounding and LNB_observation

A measure of the magnitude of the entrainment effect

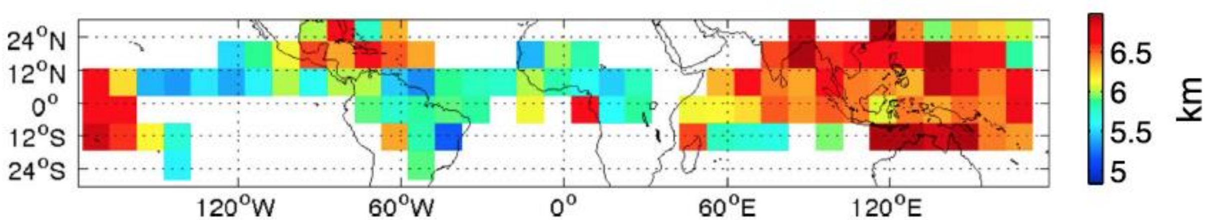
LNB_sounding –LNB_CTH mean= 0.81km



LNB_sounding –LNB_maxMass mean= 3.51km



LNB_sounding –LNB_CBH mean= 5.72km



- Deep convective clouds over the Warm Pool tend to be more diluted than those over the tropical Africa and Amazonia.

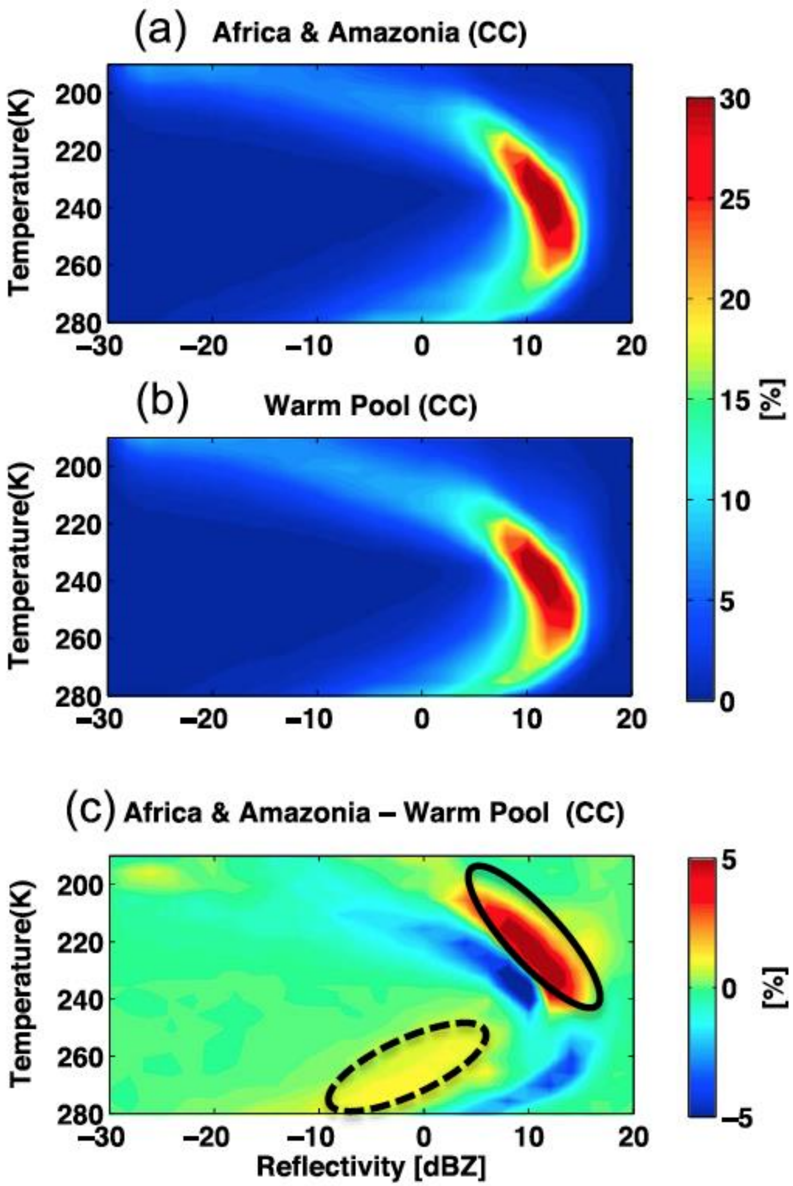
Internal vertical structure of convective cores

CFTD

less diluted core

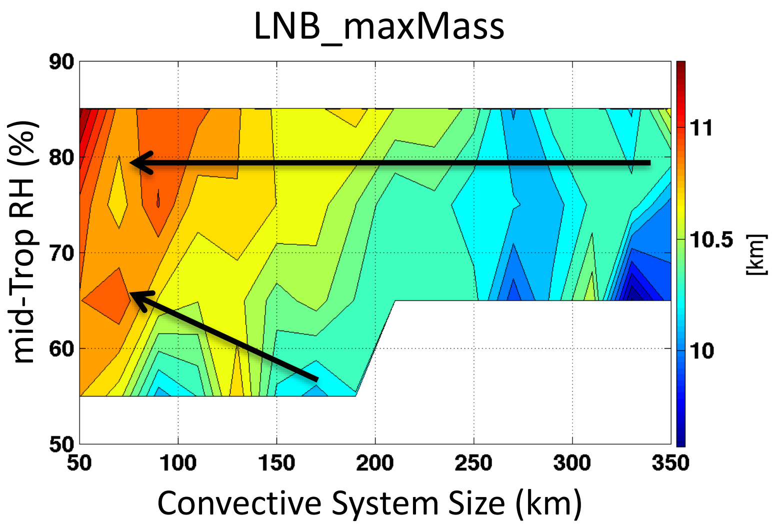
more diluted core

difference

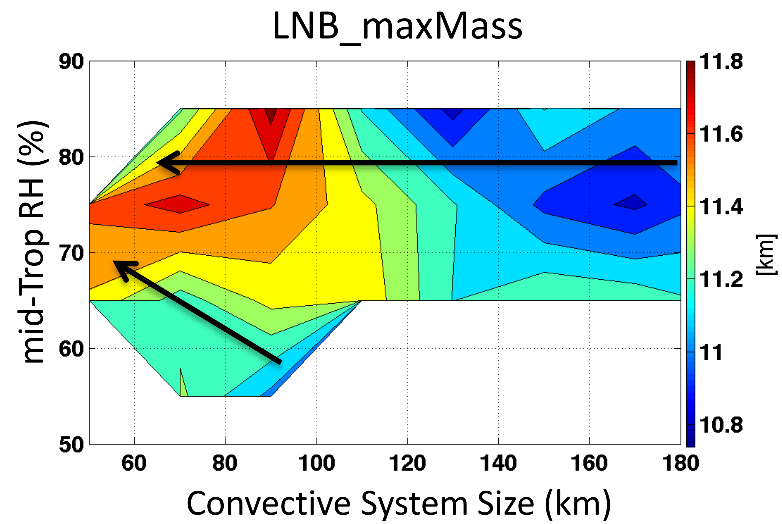


- Tropical land has more occurrences of larger radar at higher altitudes.
- Attenuation due to heavy precipitation is more severe in tropical land than the Warm Pool.

Ocean

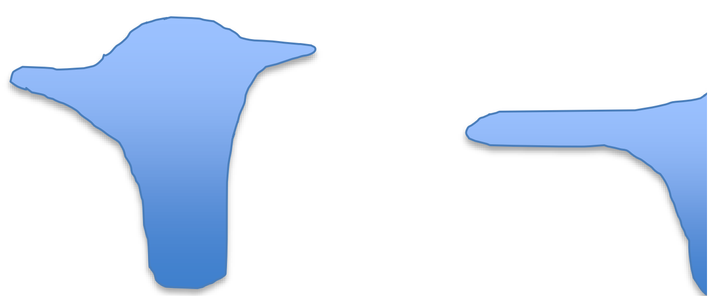


Land



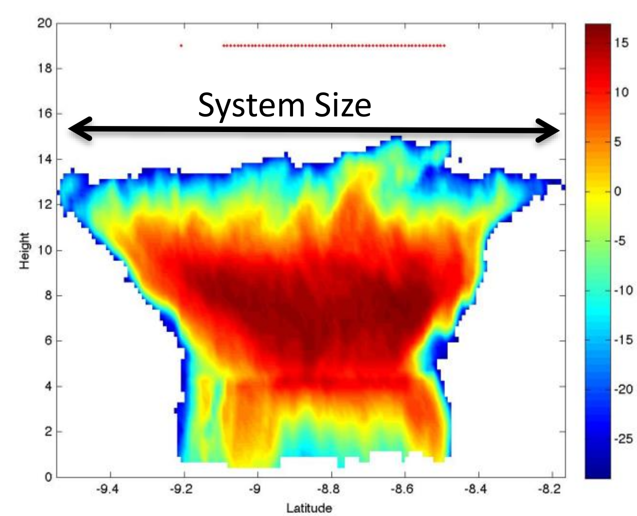
- Higher LNB maxMass are associated with a moister midtroposphere, because a moister environment reduces the effect of entrainment dilution. The trend is especially pronounced for smaller systems.

- LNB_maxMass decreases with convective system size
size dependence has to do with convective life stage

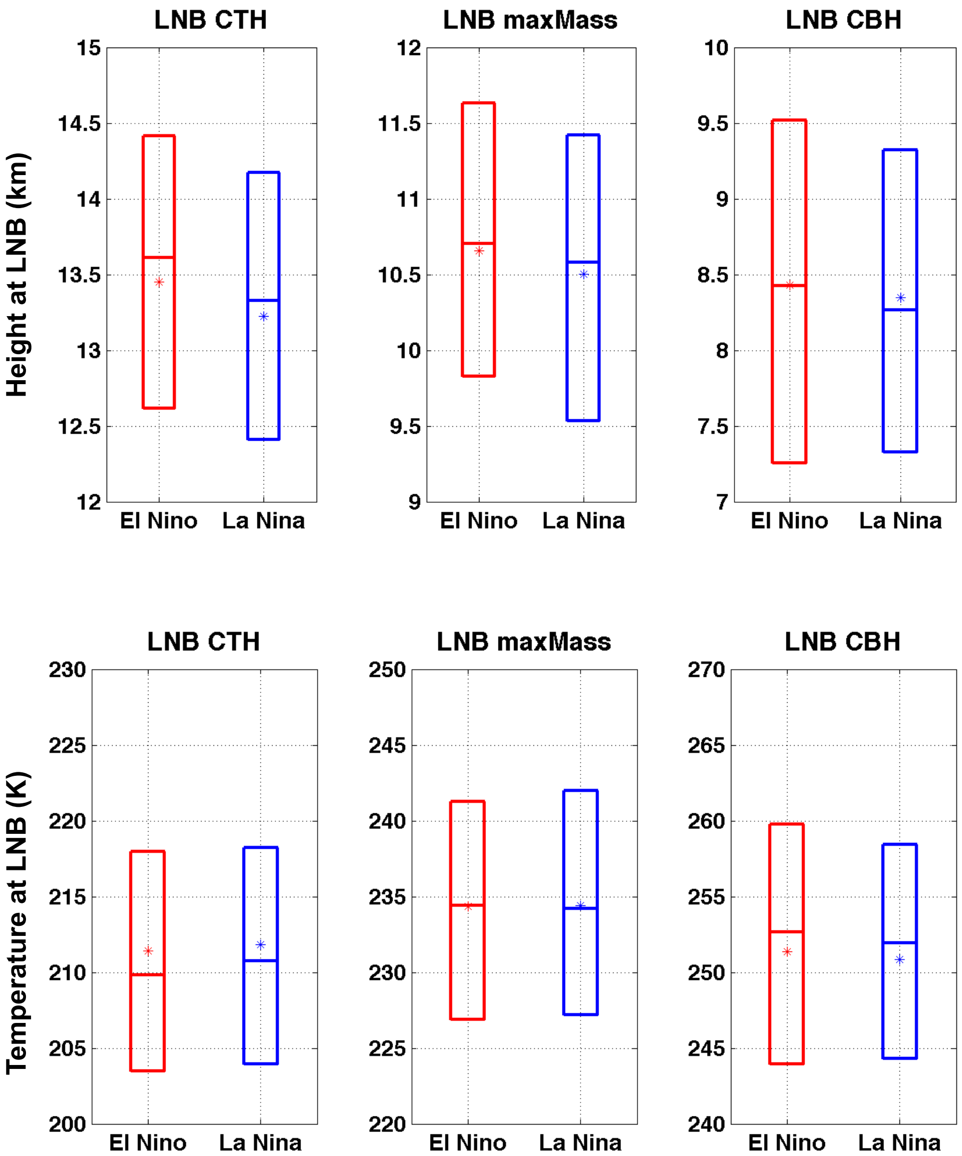


Younger Stage

C

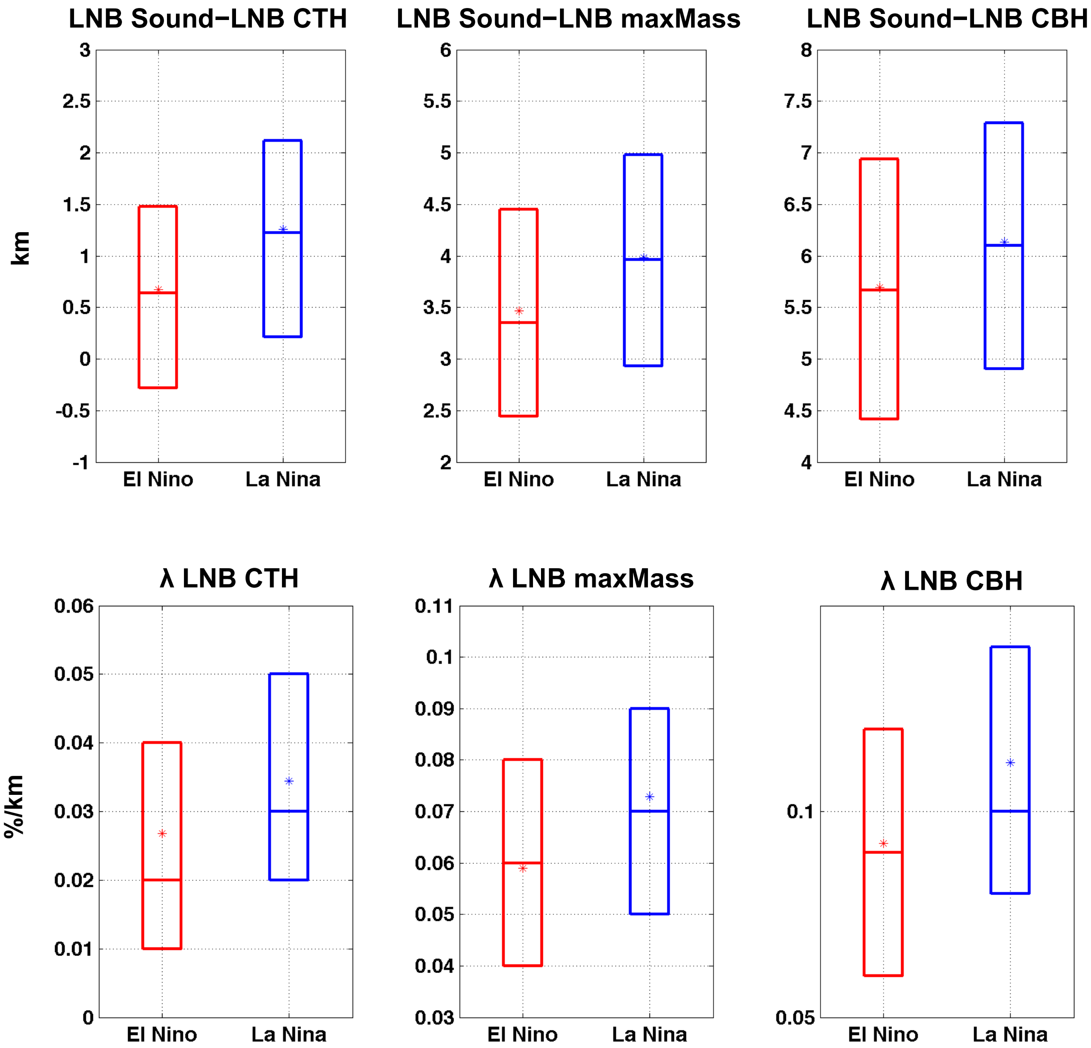


LNB during El Niño and La Niña over the whole Tropics



- Student's T-test suggests that LNB_observation is more likely to stay the same or slightly elevates in a warmer world, but the temperature at LNB_observation is insensitive to climate changes, which supports FAT hypothesis.
- FAT hypothesis is most evident at LNB_maxMass, and this can be because this level is most relevant to convective mass outflow and convective transport.

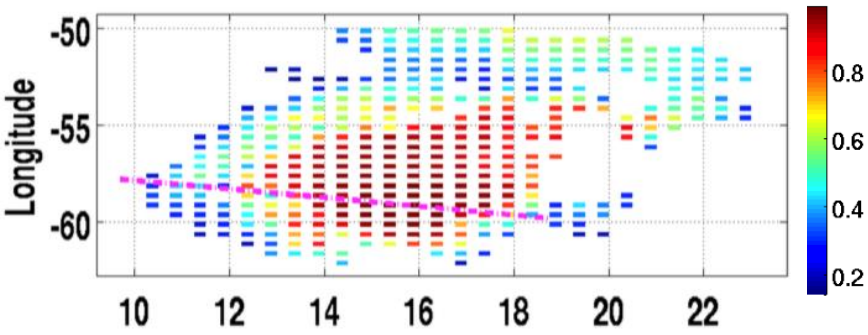
Convective dilution El Niño and La Niña over the whole Tropics



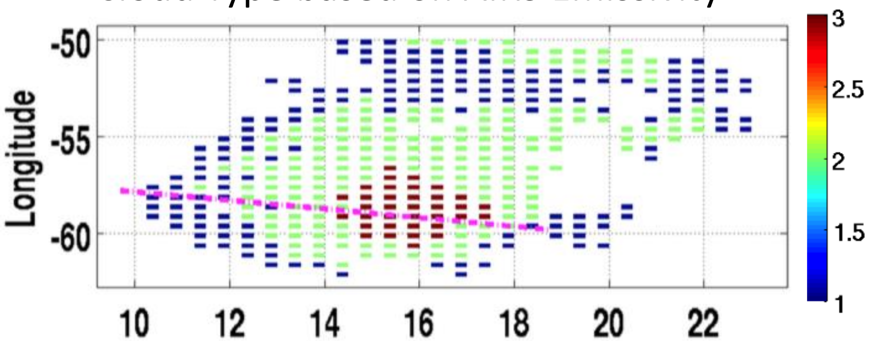
- Deep convective clouds during La Niña are more diluted than those during El Niño.

Preliminary Results: Fraction of thin anvils over more and less diluted convection

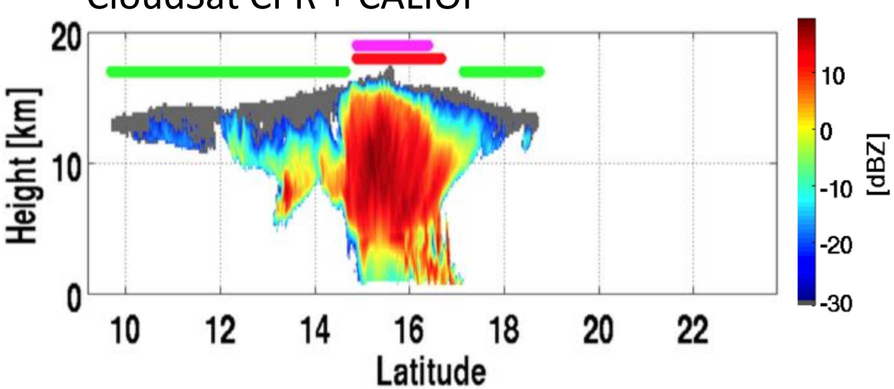
AIRS Emissivity

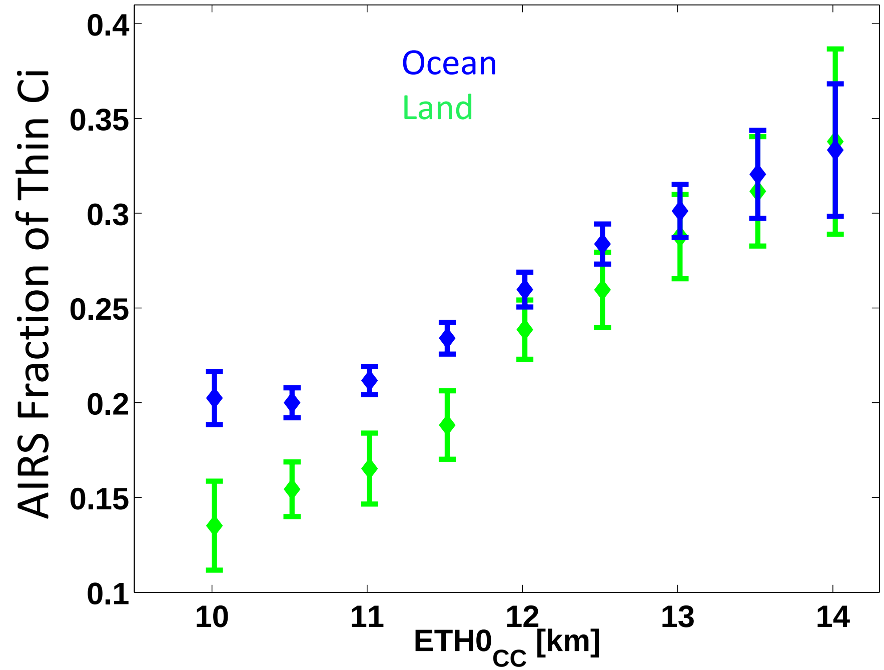


Cloud Type based on AIRS Emissivity



CloudSat CPR + CALIOP





More Diluted ↔ Less Diluted

- Fraction of thin cirrus increase as convective strength.

Conclusions:

- **The difference between LNB_sounding and LNB_observation can be interpreted as a measure of convective dilution**: the Warm Pool is more diluted than the two tropical land regions (Africa and Amazonia).

- In a warmer world:

(1) LNB_observation tends to stay the same, or slightly elevate.

(2) **Temperature at LNB_observation stay the same, supporting FAT hypothesis.**

(3) Deep convective clouds tend to be less diluted.

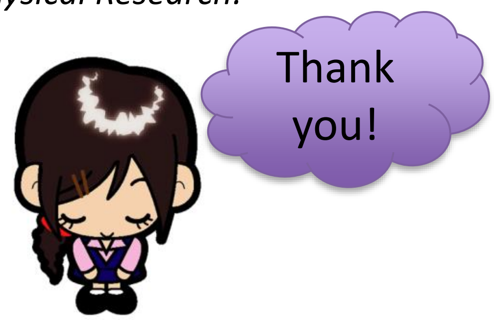
(4) Fraction of thin cirrus tends to increase

➔ more convective ➔ more UT warming ➔ less convective : Negative Feedback?

Reference:

Takahashi, H., Luo, Z. J., & Stephens, G. L. (2018). Convective Detrainment Levels and Convective Dilution during El Niño and La Niña, in prep.

Takahashi, H., Luo, Z. J., & Stephens, G. L. (2017). Level of neutral buoyancy, deep convective outflow, and convective core: New perspectives based on 5 years of CloudSat data. *Journal of Geophysical Research: Atmospheres*, *122*(5), 2958-2969. DOI:10.1002/2016JD025969.



The mean difference of CTH – ETH 20 dBZ

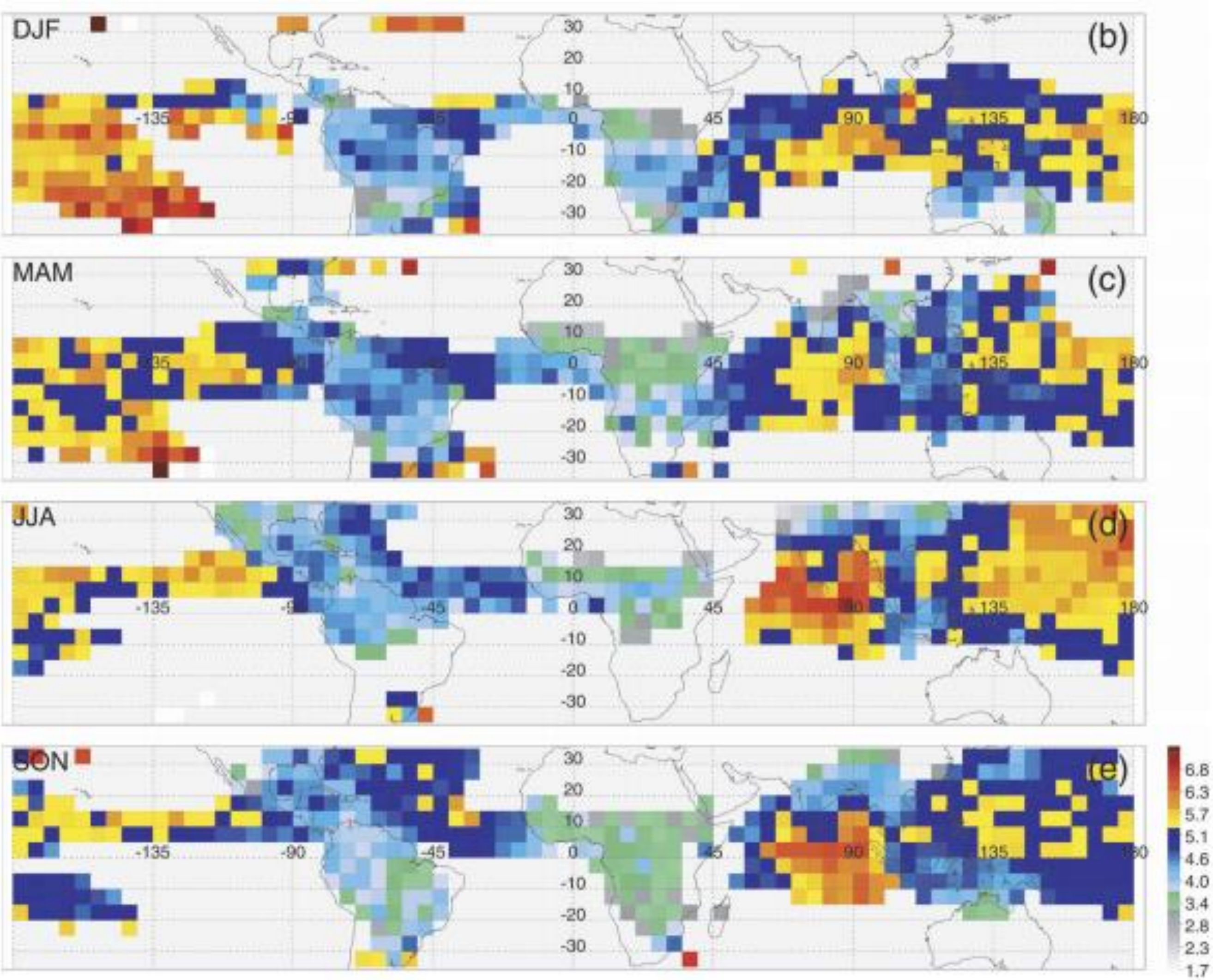


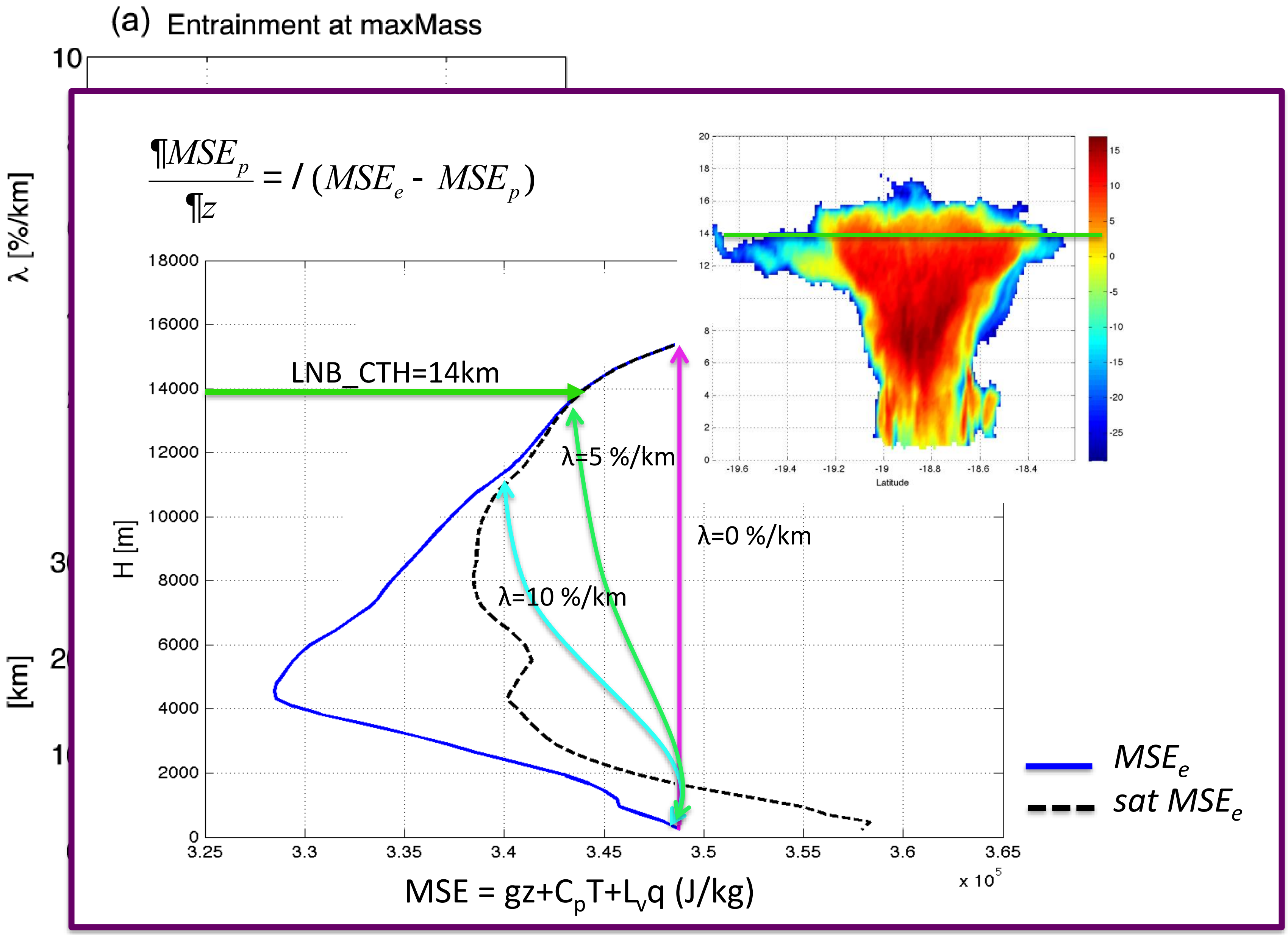
FIG. 10. The mean differences of cloud-top height calculated from minimum T_{B11} and the maximum 20-dBZ echo-top height for CCFs (≤210 K with 2A25 rain) in 5° × 5° boxes and their seasonal variations. Units are height differences in km that the 20-dBZ echo top is below the IR top height.

- ✓ (1) Smaller over land than over ocean.
- ✓ (2) Central Africa has smallest distance.
- ➢ (3) Largest distance is over west Pacific during DJF than JJA.
- ✓ (4) Deep convection over the tropical Africa and Amazon tends to be less diluted from JJA to SON.
- ✓ (5) Largest distance is over Indian Ocean during MAM & JJA.

Liu et al., 2007

Entrainment and the Size of Convective Cores

$$\frac{\partial MSE_p}{\partial z} = \lambda (MSE_e - MSE_p)$$



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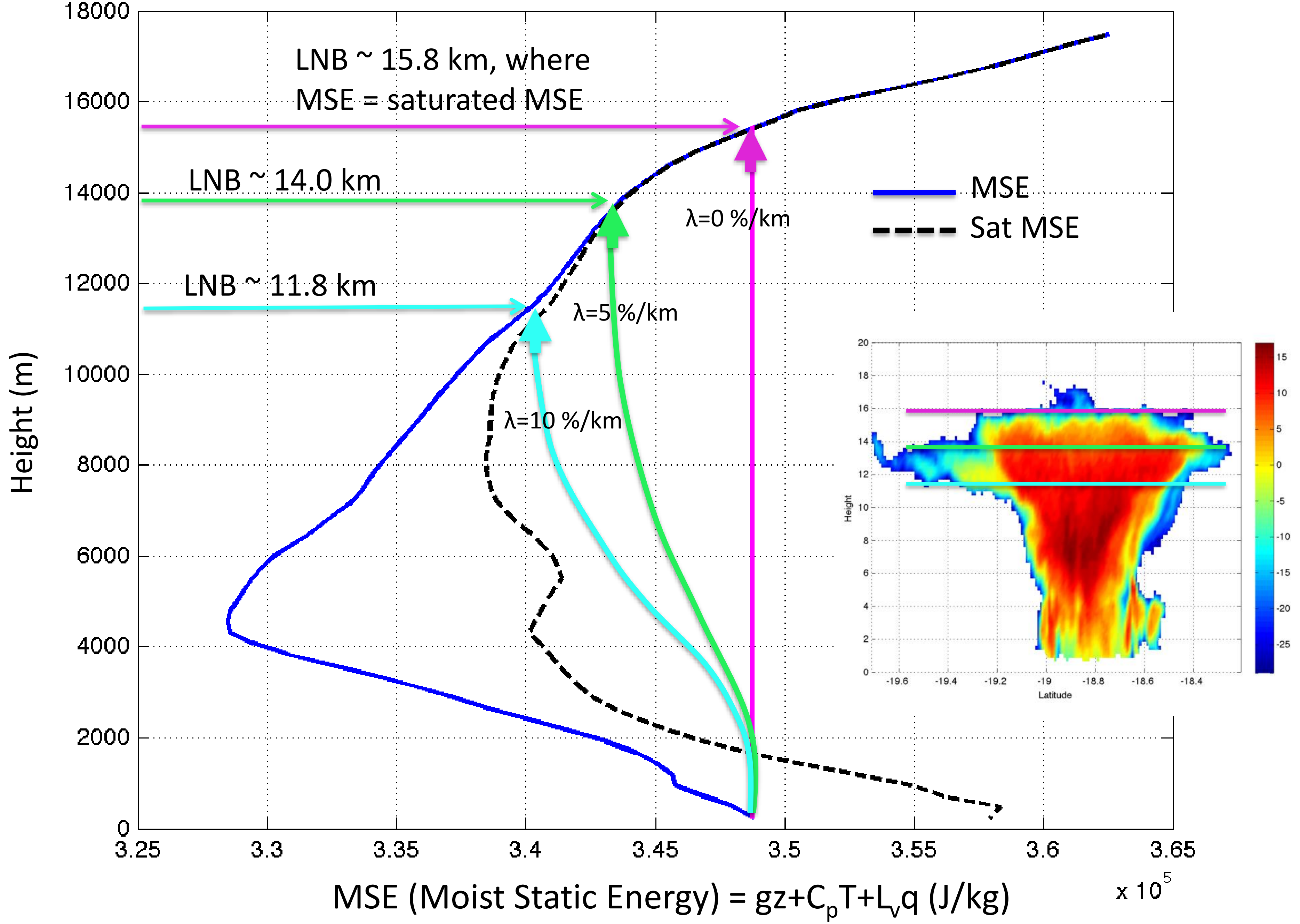
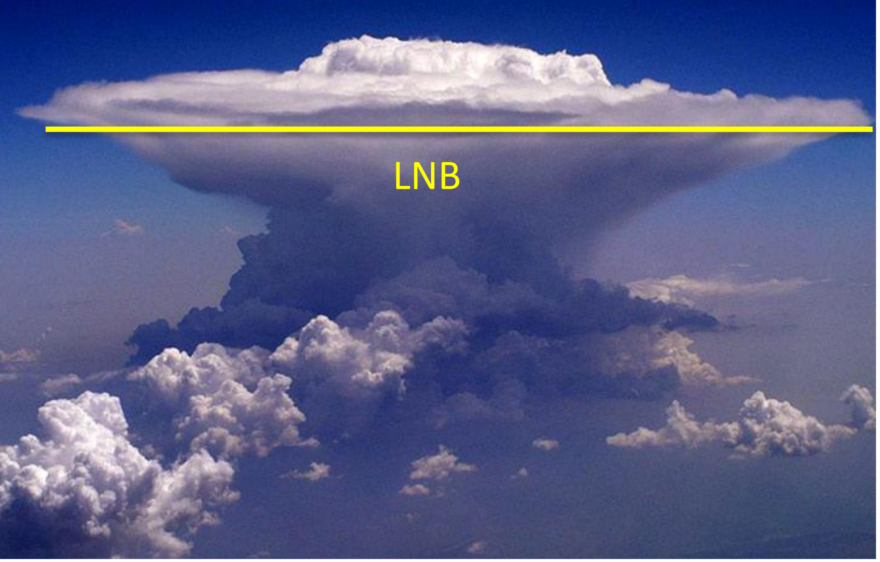
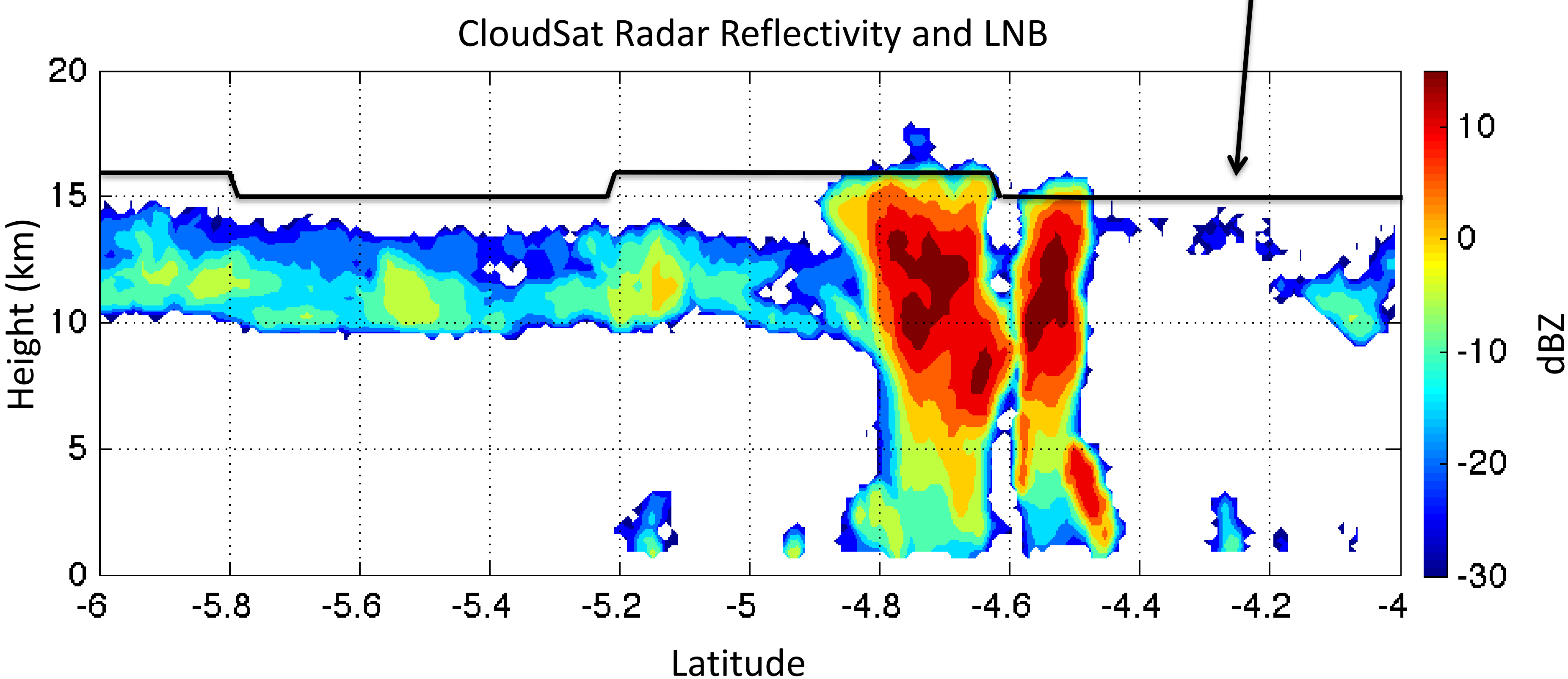


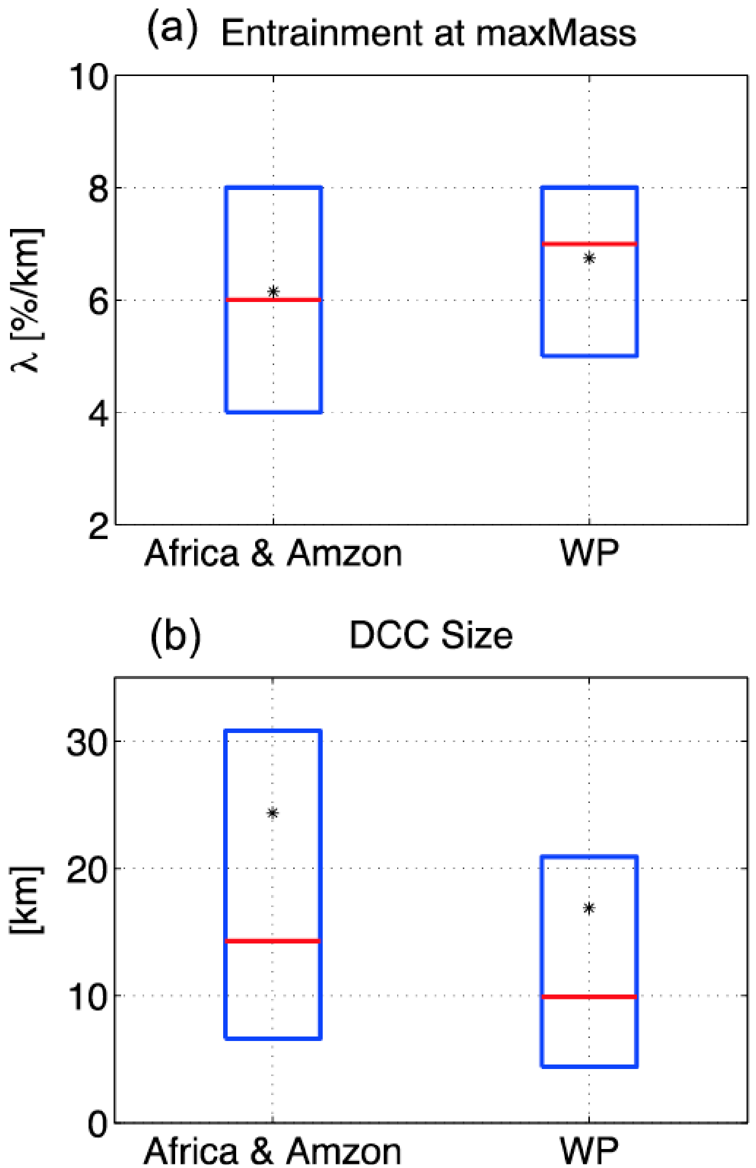


Why don't we find the LNB from Cloud Object from CloudSat instead of using parcel theory!?

LNB based on parcel theory

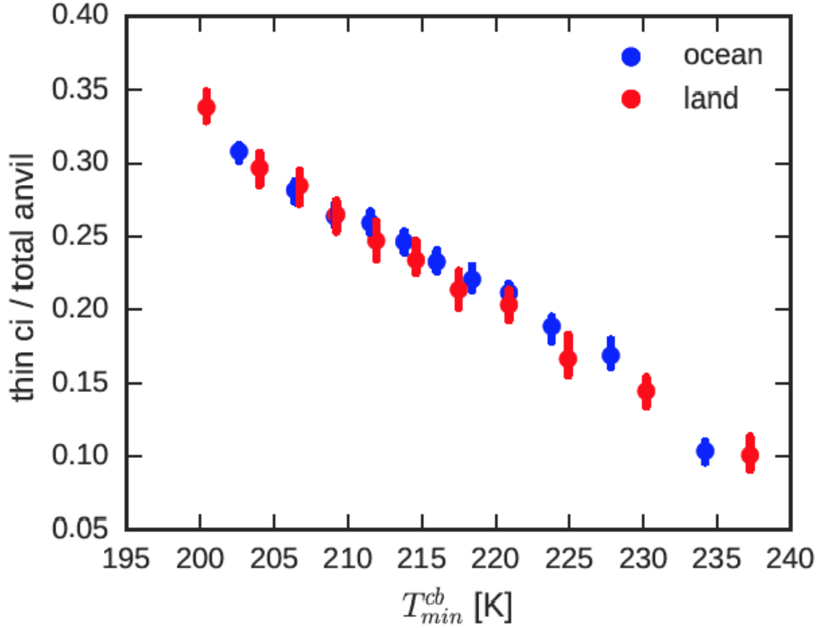


Entrainment and the Size of Convective Cores



- The convective entrainment rates are smaller for the Warm Pool than the two land regions.
- A negative correlation between DCC size and bulk entrainment rate.
- Larger convective cores are better protected from the environment and thus are less diluted by entrainment.

During Mature Stage
(fraction of CC btw 0.1-0.3%)



The fraction of thin cirrus (ε<0.5) increases as min CTT within convective core decreases.

(Protopapadaki et al., ACP 2017)